Measurement of the misidentification rate of $e \to \tau_h$

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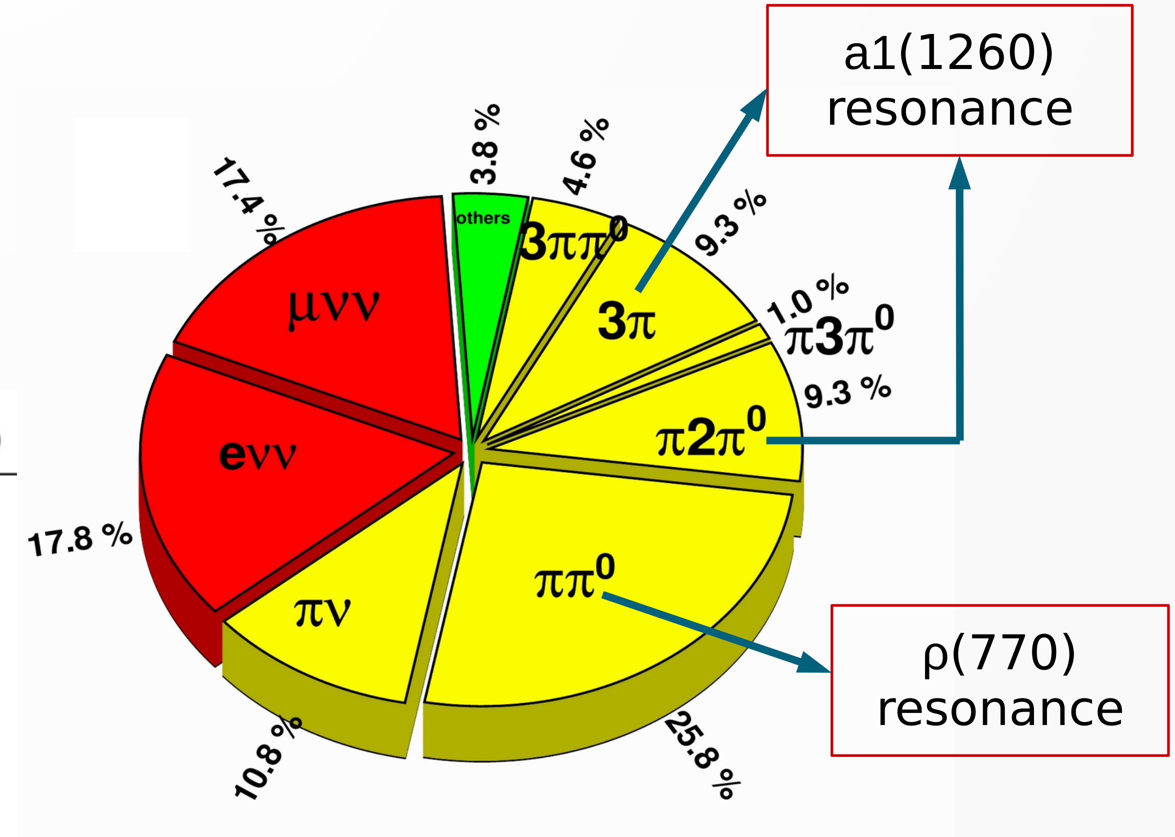
Motivation

- H→ ττ analysis: Higgs coupling with leptons and BSM
- τ leptons decay before reaching CMS detector: $\tau_\tau = 2.9 \times 10^{-13} s$ how is it detected?
- Need to use its decay modes

  ~35% Leptonic

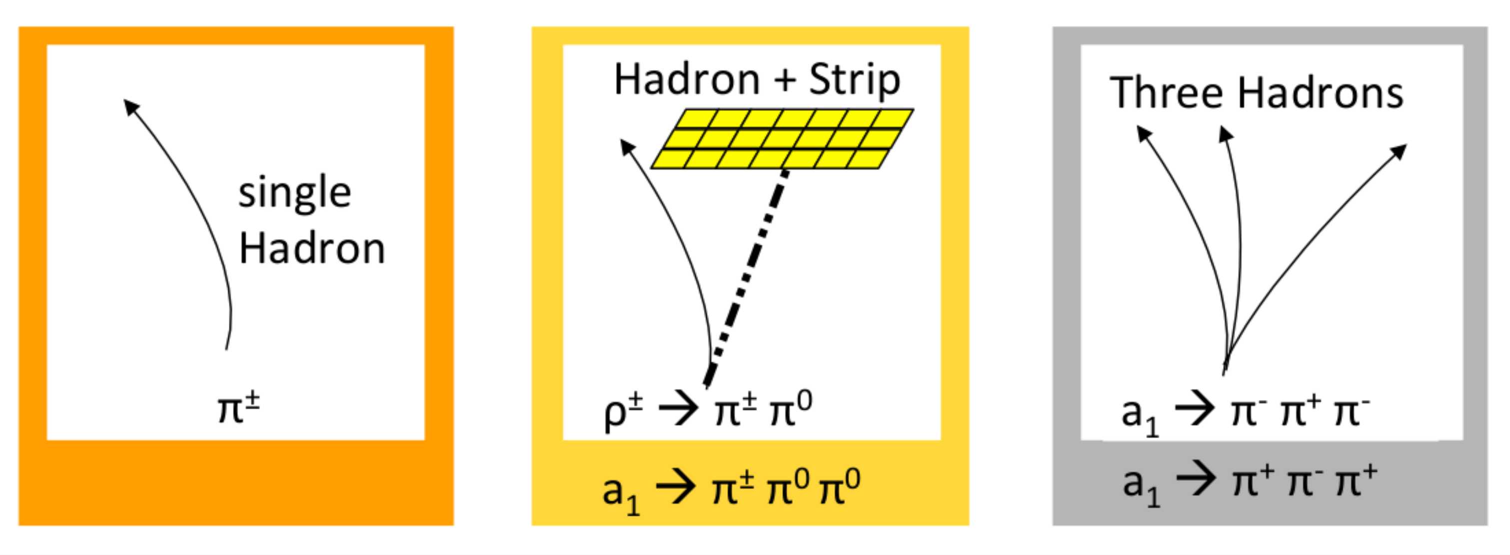
  ~65% Hadronic

Decay mode	Resonance	Branching ratio (%)
$h^- \nu_\tau$		11.5
$h^- \pi^0 \nu_\tau$	$\rho(770)$	25.9
$h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other		3.3



The hadronic Tau reconstruction

- The hadron-plus-strip (HPS) algorithm:
  - Charged hadron ("*prong*"): track in the tracker and ECAL/HCAL deposit
  - Neutral hadron (π^0): produces a "*strip*" in the ECAL by $\gamma\gamma$ decay
- Various categories → search for matching with one of the τ decay modes



Strip: a narrow $\Delta\eta \times \Delta\varphi$ region in which ECAL deposits are found

Why this measurement?

- Electron can fake the τ_h signature:
  - Electron itself mimicks prong (charged hadron)
  - Bremsstrahlung photons mimick π^0 photons (i.e. a strip)

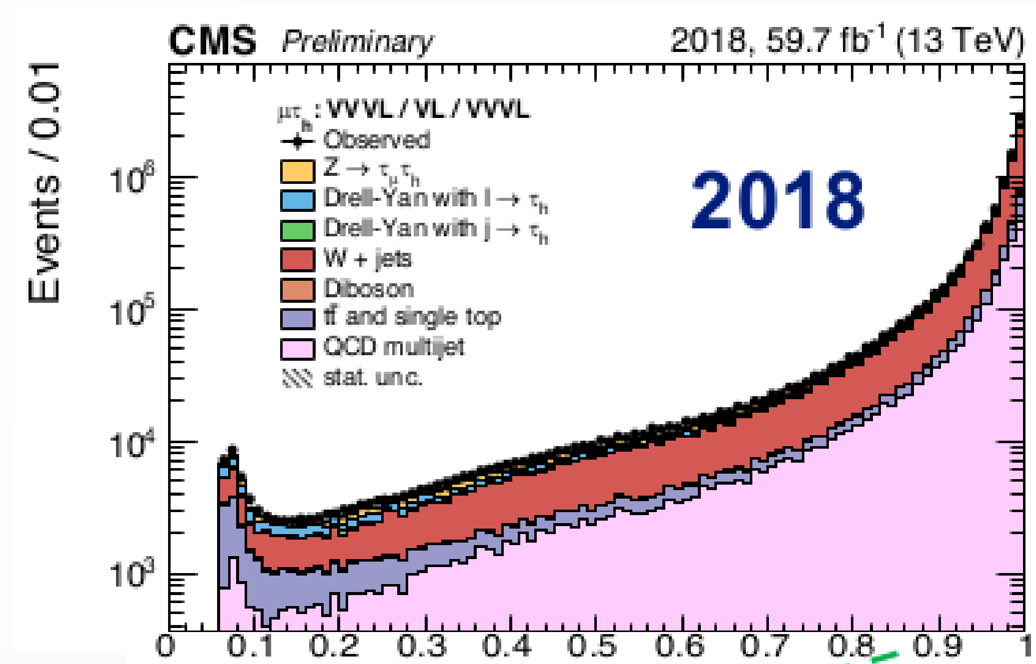
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$ → 1 strip + 1 prong: HPS matching

- Montecarlo simulations have to model the fake rate in order to correctly reproduce data

→ correction scale factor measured

The DeepTau discriminator

- Deep neural network used to discriminate hadronic taus from mimicking objects
- Used the one against electrons
- Working points are defined based on efficiency



Looser

Tighter

$$\frac{p_\tau}{p_\tau + p_e}$$

Background rejection increasing→tighter WP

The TAG & PROBE method

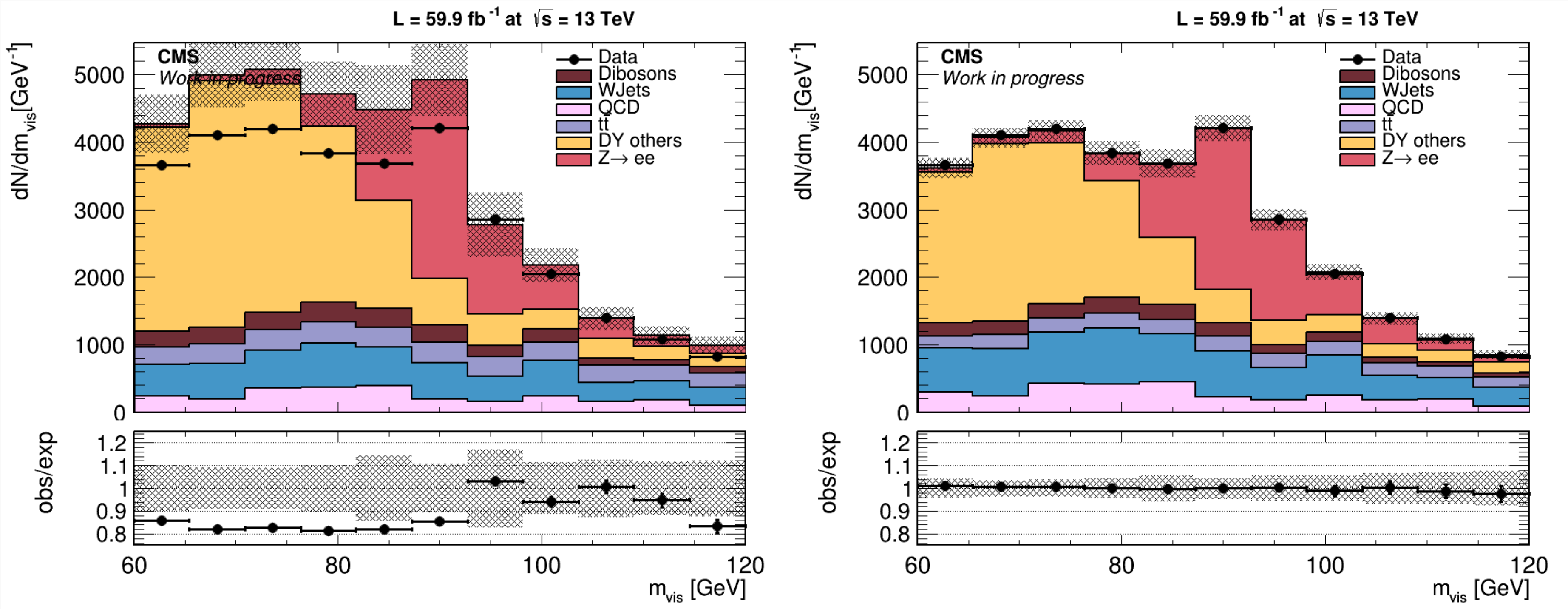
- We want events in which two such particles can be found:
  - A **well identified and isolated electron**, matching the trigger object → the TAG
  - A particle which has matched one of the decay modes from HPS: that is a τ_h **which has passed "*loose preselection criteria*"** → the PROBE
- If we look only at Z→ee events we are sure that the Probe is indeed a fake.

So we can calculate the *PRE-FIT* fake rate ε as the efficiency of the anti-electron discriminator:	$\epsilon = \frac{N^{pass}_{Z\to ee}}{N^{pass}_{Z\to ee} + N^{fail}_{Z\to ee}}$

T&P: maximum likelihood fit

Maximum likelihood fit: parameter of interest (POI)
$r = \varepsilon' / \varepsilon$ (it's the ***scale factor***)

- Fit is performed on visible mass, 60 GeV - 120 GeV



Medium WP, Barrel

Results

BARREL $(\lvert\eta\rvert < 1.460)$	pre-fit FR	post-fit FR	scale factor
VVLoose	$(4.5 \pm 0.5) \times 10^{-2}$	$(5.8 \pm 0.7) \times 10^{-2}$	$r = 1.280^{+0.014}_{-0.015}$
VLoose	$(2.4 \pm 0.3) \times 10^{-2}$	$(3.3 \pm 0.4) \times 10^{-2}$	$r = 1.368^{+0.029}_{-0.033}$
Loose	$(1.0 \pm 0.1) \times 10^{-2}$	$(1.31 \pm 0.18) \times 10^{-2}$	$r = 1.31^{+0.05}_{-0.05}$
Medium	$(3.9 \pm 0.4) \times 10^{-3}$	$(5.0 \pm 0.9) \times 10^{-3}$	$r = 1.35^{+0.09}_{-0.09}$
Tight	$(1.14 \pm 0.13) \times 10^{-3}$	$(1.5 \pm 0.4) \times 10^{-3}$	$r = 1.32^{+0.22}_{-0.22}$
VTight	$(4.8 \pm 0.5) \times 10^{-4}$	$(7 \pm 3) \times 10^{-4}$	$r = 1.4^{+0.4}_{-0.4}$
VVTight	$(2 \pm 0.2) \times 10^{-4}$	$(2.1 \pm 0.7) \times 10^{-4}$	$r = 1.4^{+0.9}_{-0.9}$
ENDCAP $(\lvert\eta\rvert > 1.558)$	pre-fit FR	post-fit FR	scale factor
VVLoose	$(8.7 \pm 0.9) \times 10^{-2}$	$(1.14 \pm 0.13) \times 10^{-1}$	$r = 1.318^{+0.016}_{-0.017}$
VLoose	$(4.4 \pm 0.5) \times 10^{-2}$	$(5.8 \pm 0.8) \times 10^{-2}$	$r = 1.314^{+0.033}_{-0.039}$
Loose	$(1.9 \pm 0.2) \times 10^{-2}$	$(2.7 \pm 0.5) \times 10^{-2}$	$r = 1.38^{+0.07}_{-0.08}$
Medium	$(9 \pm 1) \times 10^{-3}$	$(1.21 \pm 0.12) \times 10^{-2}$	$r = 1.35^{+0.13}_{-0.12}$
Tight	$(2.7 \pm 0.3) \times 10^{-3}$	$(4 \pm 1) \times 10^{-3}$	$r = 1.51^{+0.27}_{-0.29}$
VTight	$(9.3 \pm 1.1) \times 10^{-4}$	$(6.5 \pm 6.5) \times 10^{-4}$	$r = 0.7^{+0.8}_{-0.7}$
VVTight	$(4.2 \pm 0.5) \times 10^{-4}$	$(4.2 \pm 4.2) \times 10^{-4}$	$r = 1.0^{+1.6}_{-1.0}$

Statistic is very low: Large uncertainty

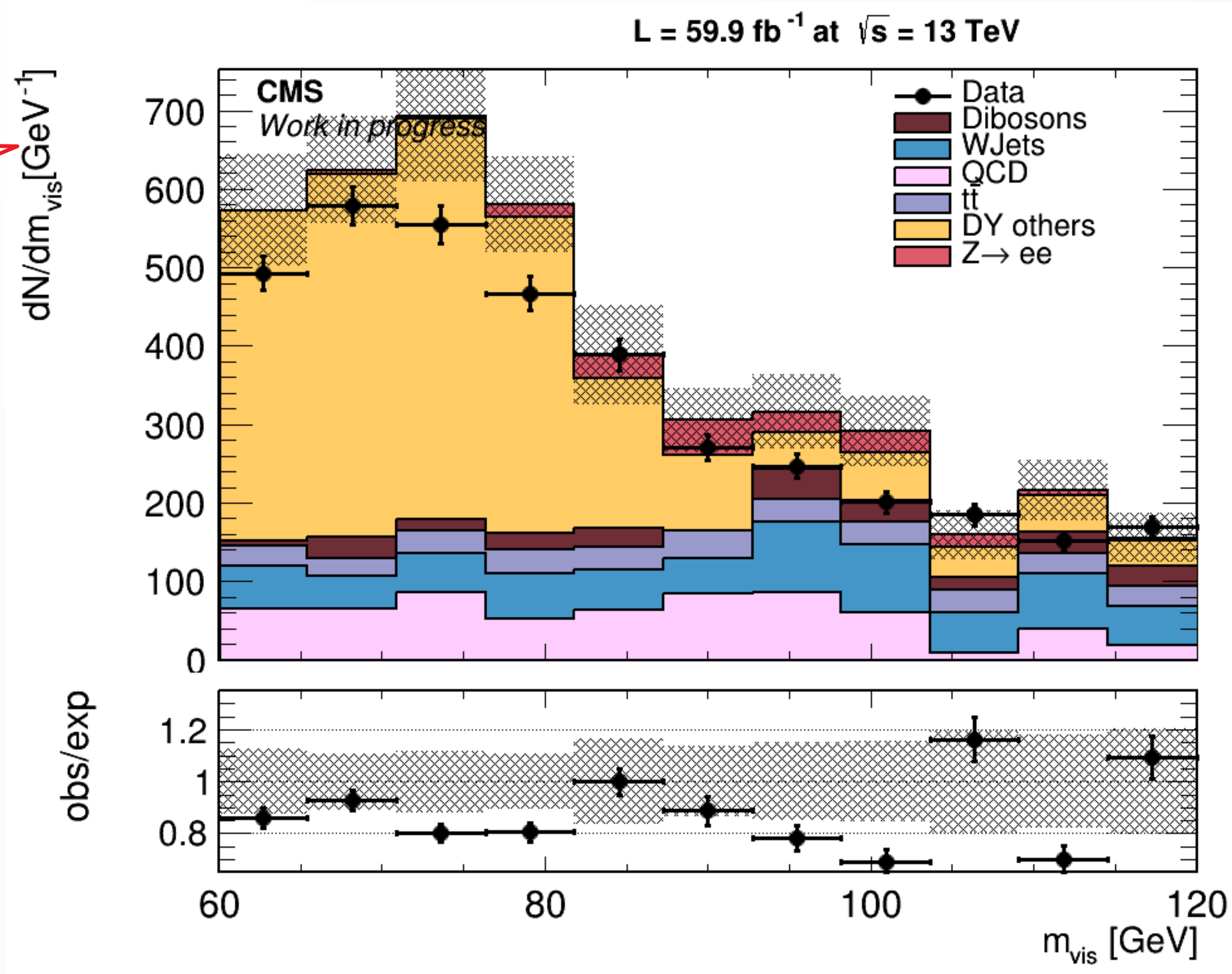
First step for CMS recommendation on scale factors for $e \to \tau_h$ fake rates

Why this result?

Barrel	
VTight	$r = 1.4^{+0.4}_{-0.4}$
VVTight	$r = 1.4^{+0.9}_{-0.9}$
Endcap	
VTight	$r = 0.7^{+0.8}_{-0.7}$
VVTight	$r = 1.0^{+1.6}_{-1.0}$

MAMMA MIA!

Pre-fit plot for VVTight WP, ENDCAP



- Low number of $Z \to ee$ events so that r doesn't have impact on the fit

Conclusions

- First look at DeepTau discriminator and relative fake rates
- Scale factor measured for future CMS recommendation (at least for WPs below VTight).
- For tightest WPs: DeepTau discriminator practically erases $Z \rightarrow ee$ contribution

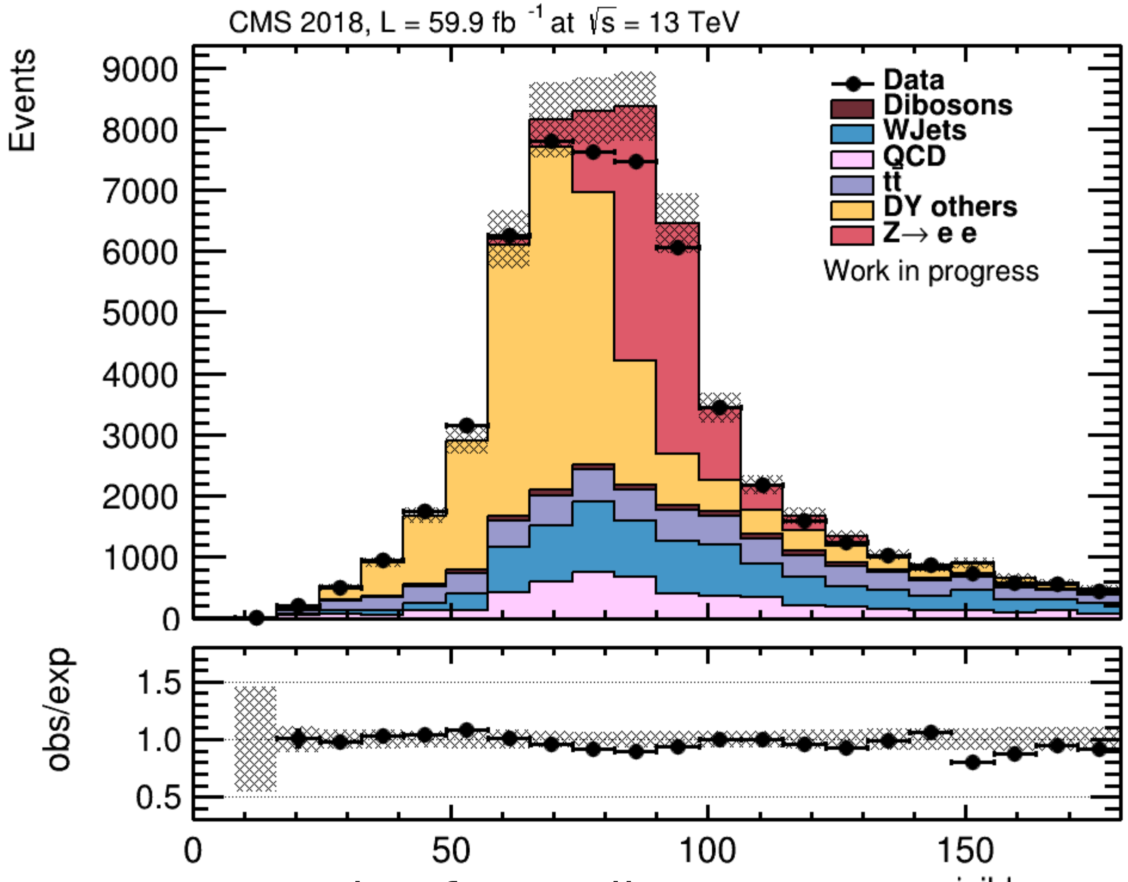
Thank you all for paying attention!

And to the HiggsTauTau group for basically everything

Backup slides

The TAG & PROBE method: pass/fail regions

- For each WP the samples undergo the discriminator:



Pass region for Medium WP

- Fake rate calculated as efficiency of anti-electron discriminator:

$$\epsilon = \frac{N^{pass}_{Z\to ee}}{N^{pass}_{Z\to ee} + N^{fail}_{Z\to ee}}$$

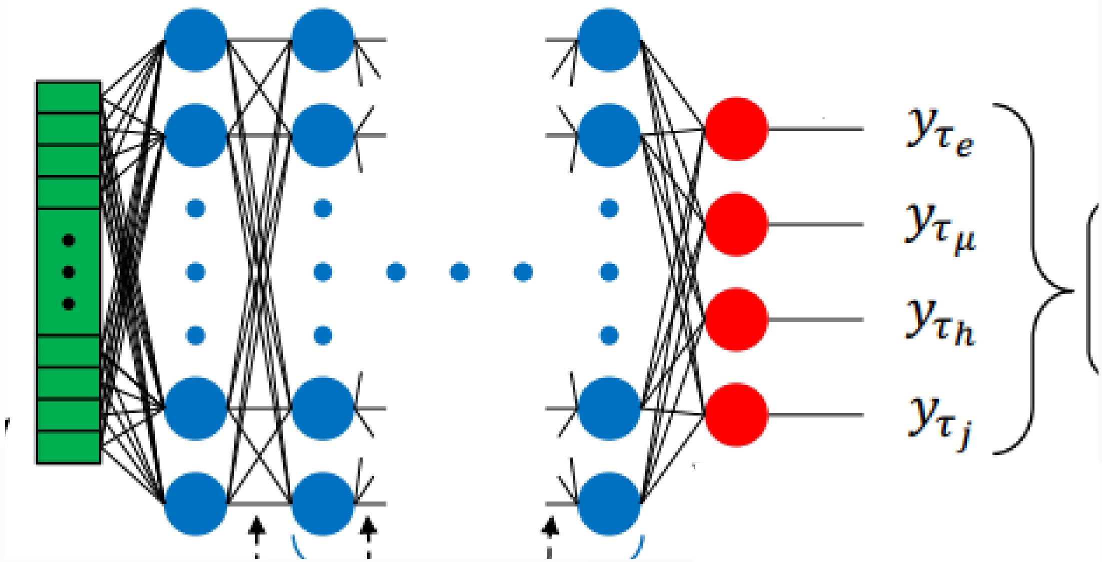
- This is the *pre-fit* misidentification rate

Cuts

Cuts:
TAG transverse momentum > 35GeV
PROBE transverse momentum >20GeV
TAG $|\eta|<2.3$
PROBE $|\eta|<2.1$
PROBE has to pass Loose against Muon, Tight against Jets
Tight requirement on electron isolation: "$I_e<0.1$"
Transverse mass <35GeV
$\Delta R>0.5$ between e and τ_h

Discriminators from DNN

- We have a DNN with 4 outputs:
  - TRUE τ_h ($y_{\tau h}$)
  - Muon ($y_{\tau\mu}$)
  - Jet ($y_{\tau J}$)
  - Electron ($y_{\tau e}$)
- Output values run from 0 to 1, telling how “confident” you can be that the particle under test is that type of object.
- With (1) you obtain a test statistic that discriminate τ from e (and so on for other sources of contamination)



$$\frac{y_{\tau_h}}{y_{\tau_h}+y_{\tau_e}} \quad (1)$$

Working points and efficiencies

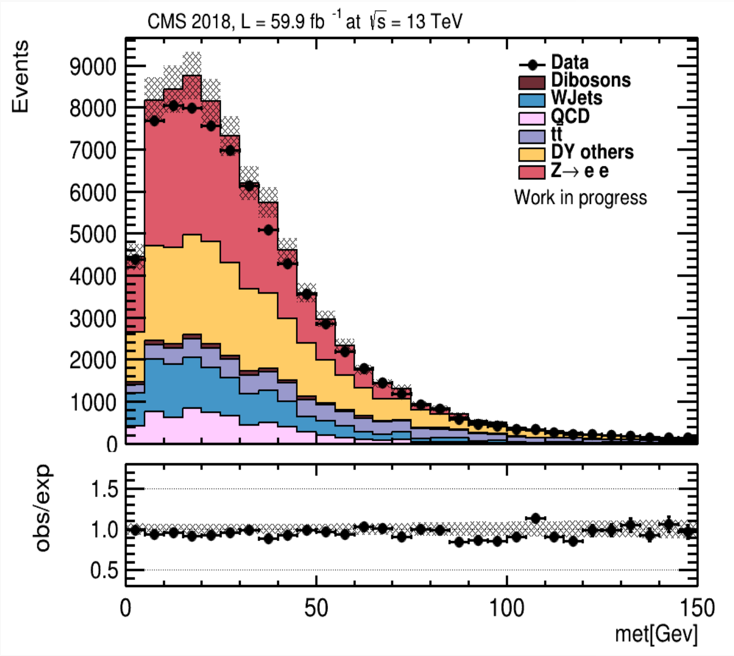
WP	VVTight	VTight	Tight	Medium	Loose	VLoose	VVLoose
Efficiency	60%	70%	80%	90%	95%	98%	99%

DNN efficiency on τ_h: number of events accepted by the discriminator over total number of events

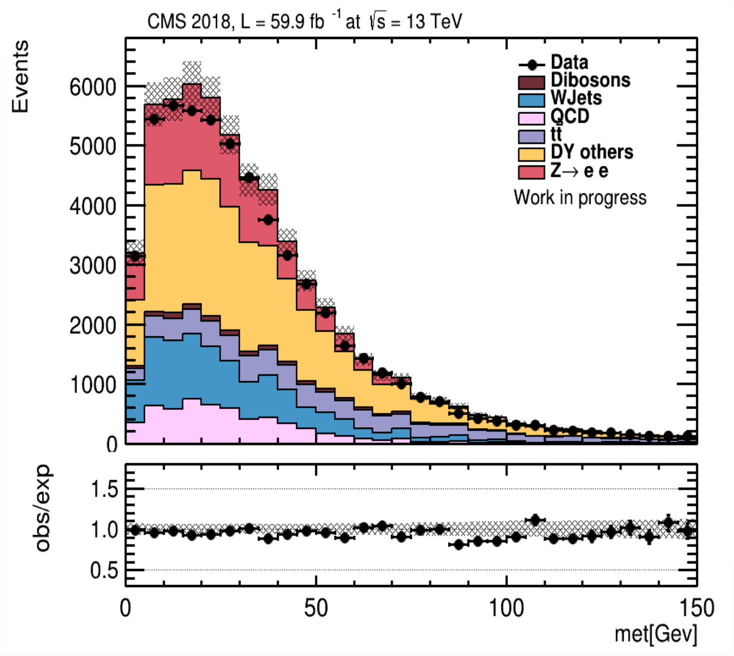
Various Working points

- Increasing WP of against electron discriminator: less contribution from Z → ee: fake rate decreasing

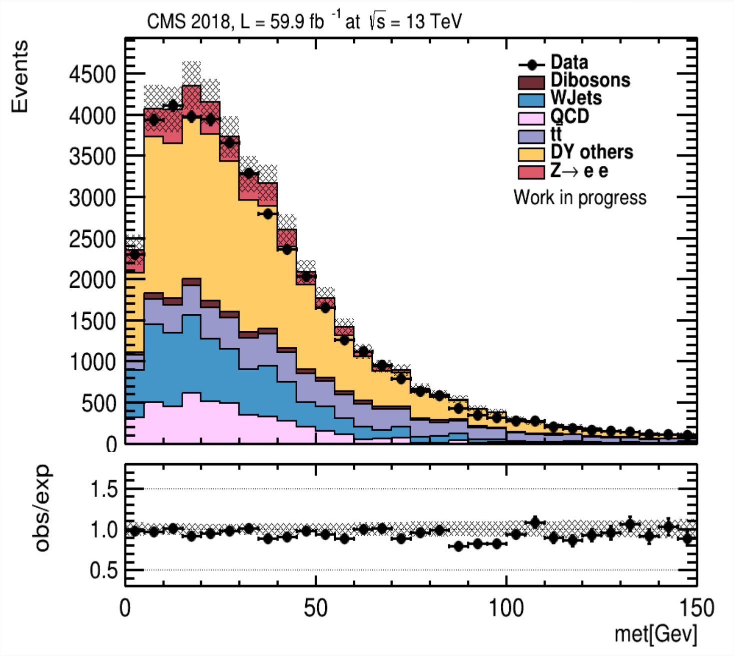
Loose



Medium

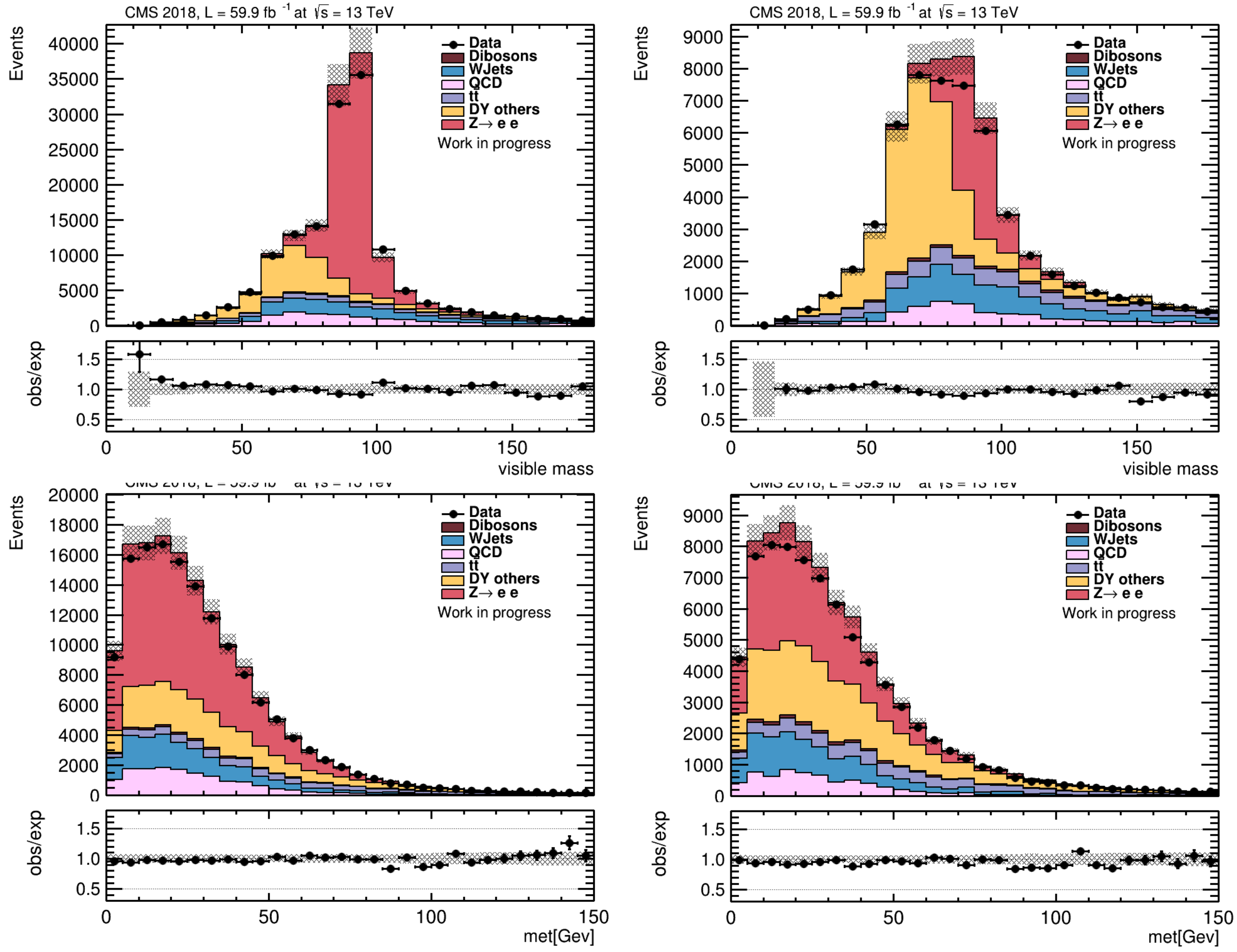


Tight



- Variable shown: missing transverse energy (PASS REGION ONLY!)

The (old) MVA discriminator



VISIBLE MASS:
Loose WP against electron.
MVA vs. DeepTau

MISSING TRANSVERSE ENERGY:
Loose WP against electron.
MVA vs. DeepTau

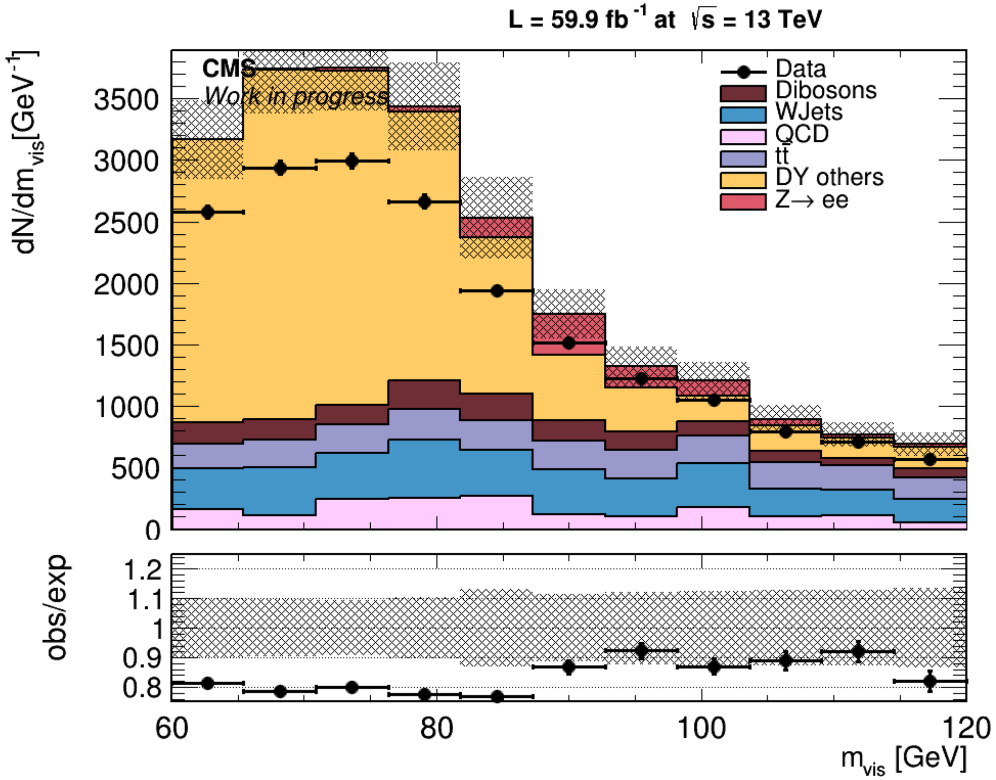
Nuisances (systematic uncertainties)

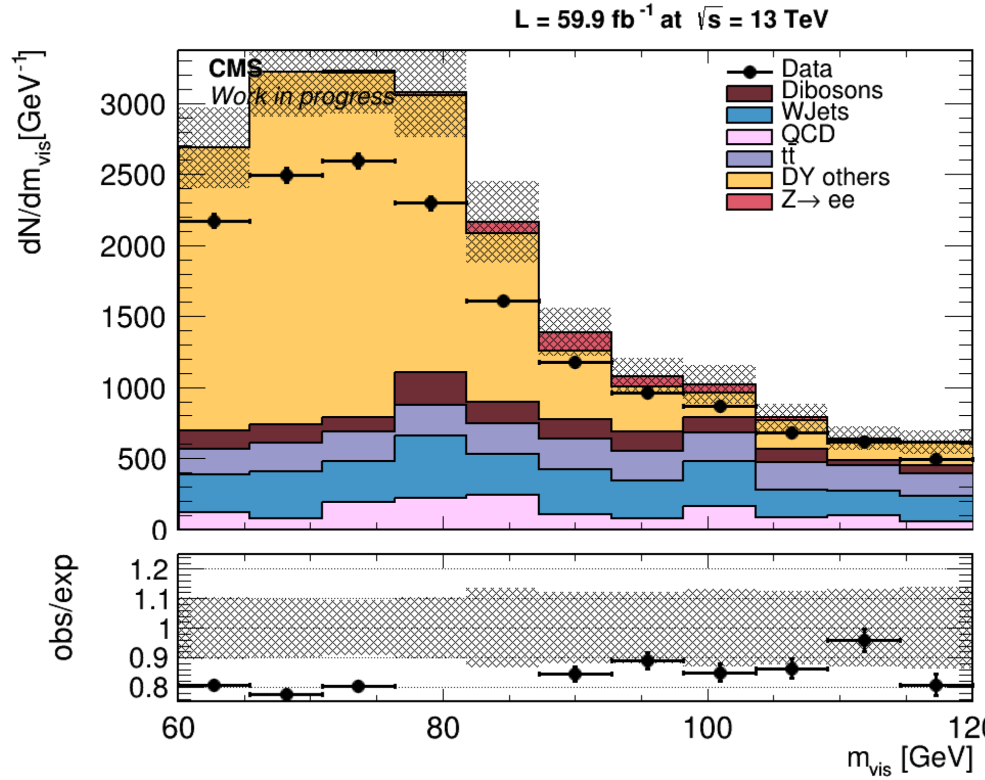
SHAPE parameters / uncertainties

Uncertainty	Affected processes	Pre-fit value
Electron energy scale	$Z \to ee$	1% B, 2.5% E [3]
τ_h energy scale	$Z \to \tau\tau$	1.5%
$e \to \tau_h$ energy scale	$Z \to ee$	3%
Visible mass resolution	$Z \to ee$	20%

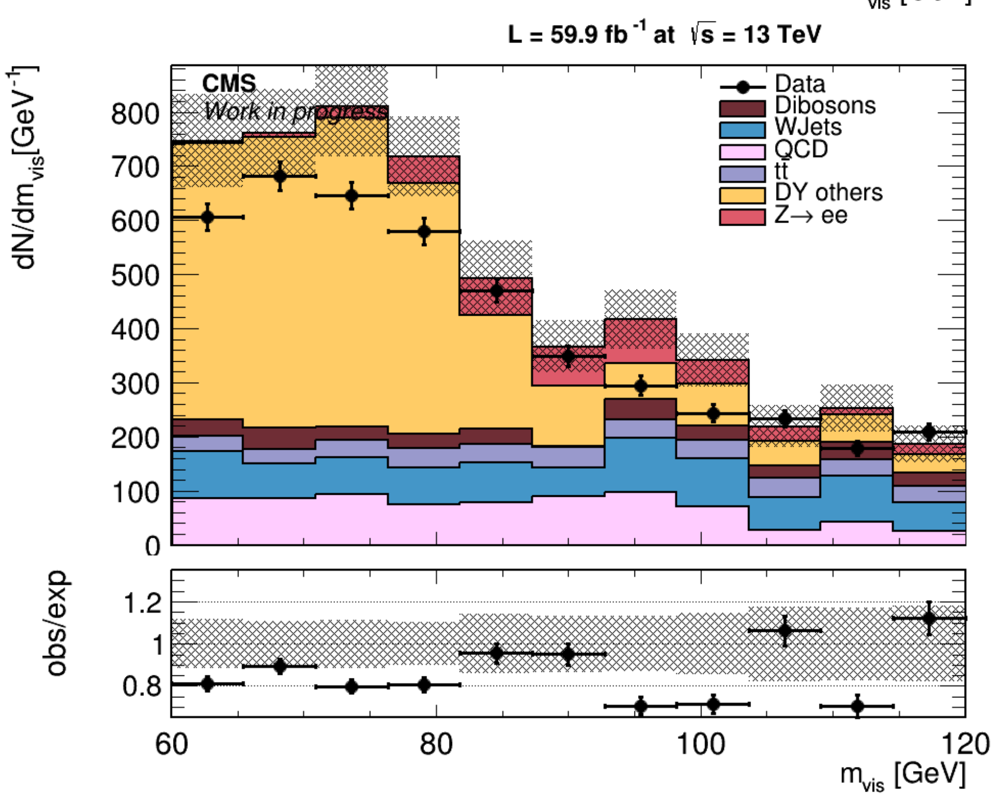
NORMALIZATION parameters / uncertainties

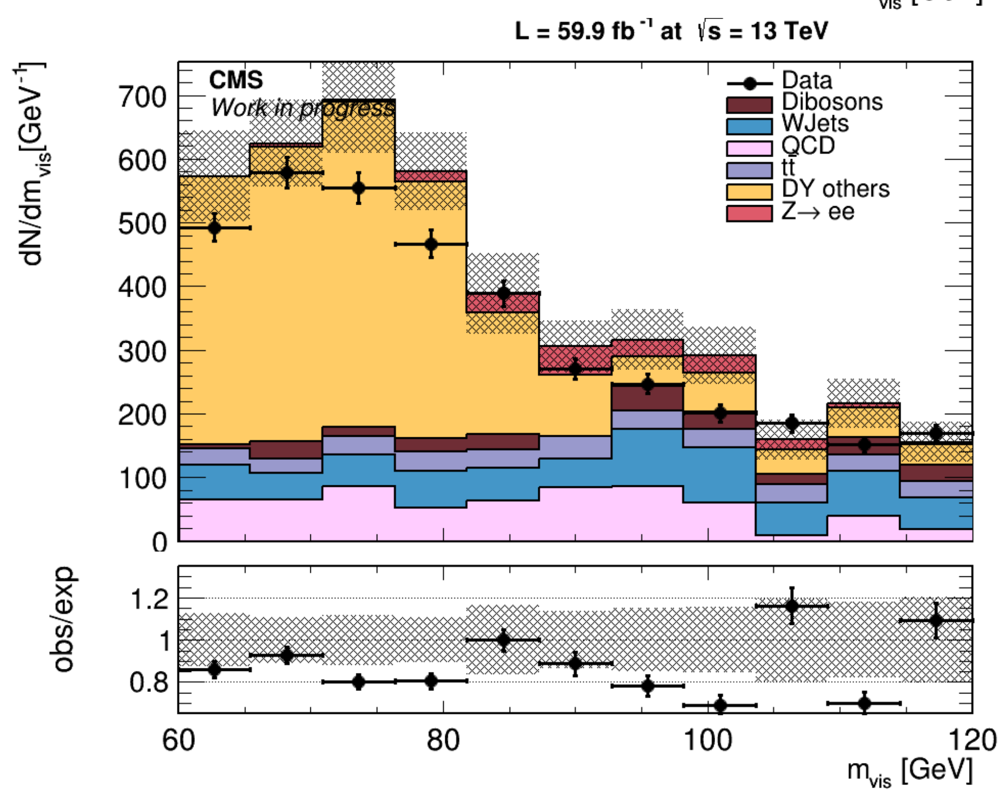
Uncertainty	Affected processes	Pre-fit value
Integrated luminosity	All	2.6%
Electron isolation/identification/trigger	All	2%
Tau identification	All	3%
$t\bar{t}$ cross section	$t\bar{t}$	10%
Diboson and single-top cross section	Diboson	10%
W+Jets normalization	W+Jets	20%
QCD normalization	QCD	20%
DY normalization	DY Others	3%
$Z \to ee$ normalization	$Z \to ee$	6%



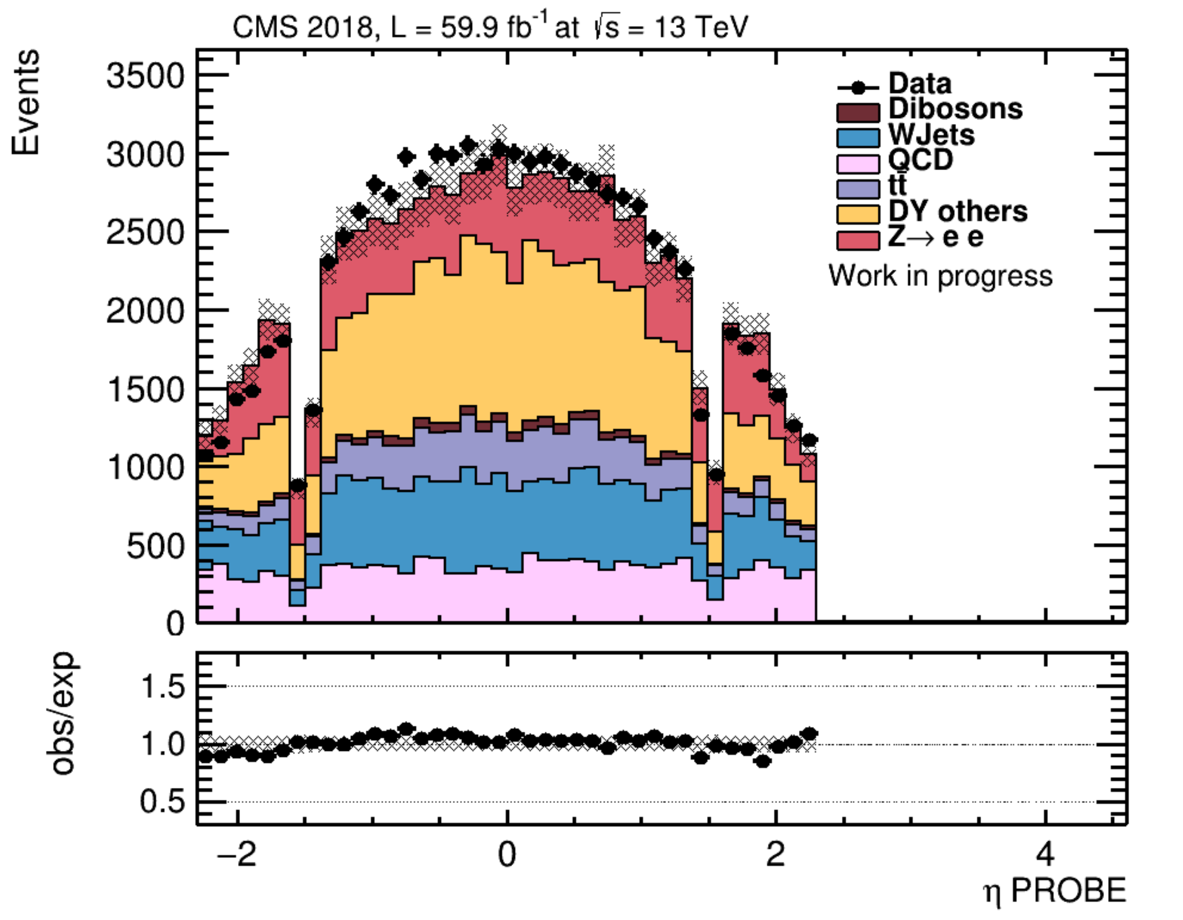


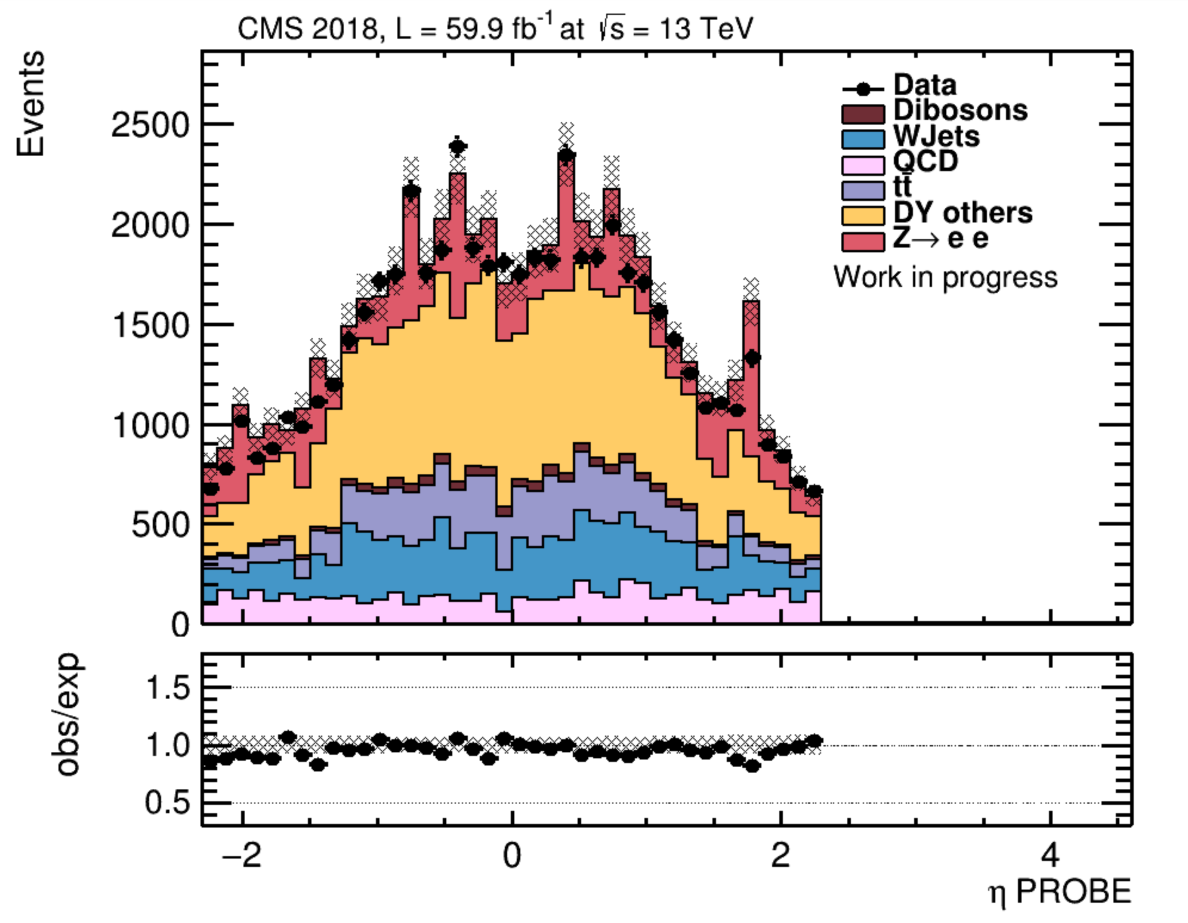
Barrel: VT and VVT





Endcap: VT and VVT


CMS 2018, L = 59.9 fb^{-1} at $\sqrt{s}$ = 13 TeV
Events
Data
Dibosons
WJets
QCD
tt
DY others
Z→ e e
Work in progress
obs/exp
η PROBE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Events
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Work in progress
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η PROBE

Try to 'improve' results

- Change binning? (not so much hope on that)
- Applying JETS-fake factors on W+Jets and QCD on DeepTau: data-driven estimation (notice bin-by-bin fluctuations for these processes)
- Abandon T&P method, fit only in pass region

Try to 'improve' results

- Use Medium against Jets for more statistic

BARREL ($\|\eta\| < 1.460$)	Medium WP SF	Tight WP SF
VVLoose	$r = 1.175^{+0.013}_{-0.014}$	$r = 1.280^{+0.014}_{-0.015}$
VLoose	$r = 1.305^{+0.020}_{-0.021}$	$r = 1.368^{+0.029}_{-0.033}$
Loose	$r = 1.29^{+0.04}_{-0.04}$	$r = 1.31^{+0.05}_{-0.05}$
Medium	$r = 1.30^{+0.08}_{-0.08}$	$r = 1.35^{+0.09}_{-0.09}$
Tight	$r = 1.33^{+0.16}_{-0.15}$	$r = 1.32^{+0.22}_{-0.22}$
VTight	$r = 1.53^{+0.30}_{-0.29}$	$r = 1.4^{+0.4}_{-0.4}$
VVTight	$r = 2.2^{+0.7}_{-0.7}$	$r = 1.4^{+0.9}_{-0.9}$

Doesn't seem to help that much

ENDCAP ($\|\eta\| > 1.558$)	Medium WP SF	Tight WP SF
VVLoose	$r = 1.137^{+0.013}_{-0.014}$	$r = 1.318^{+0.016}_{-0.017}$
VLoose	$r = 1.084^{+0.023}_{-0.024}$	$r = 1.314^{+0.033}_{-0.039}$
Loose	$r = 1.08^{+0.05}_{-0.05}$	$r = 1.38^{+0.07}_{-0.08}$
Medium	$r = 0.98^{+0.09}_{-0.09}$	$r = 1.35^{+0.13}_{-0.12}$
Tight	$r = 0.72^{+0.23}_{-0.25}$	$r = 1.51^{+0.27}_{-0.29}$
VTight	$r = 0$ (fit does not converge)	$r = 0.7^{+0.8}_{-0.7}$
VVTight	$r = 0$ (fit does not converge)	$r = 1.0^{+1.6}_{-1.0}$